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(54) **DEVICE FOR HYDRODYNAMIC FOCUSSING OF A PARTICLE-SUSPENSION IN A LIQUID FLOW CYTOPHOTOMETER.**

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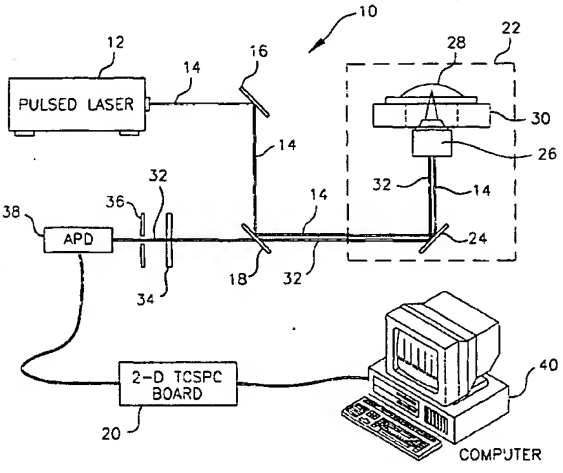
(54) Title: COMPUTER INTERFACED SCANNING FLUORESCENCE LIFETIME MICROSCOPE APPLIED TO DIRECTED EVOLUTION METHODOLOGIES AND METHODS FOR LIGHT-MEDIATED PATTERNING IN CELL SELECTION



(57) Abstract: This invention provides a method for screening large numbers of individual cells or colonies of cells using scanning microscopy coupled with fluorescence lifetime measurement and analysis, using time-correlated single photon counting. Both the imaging of the fluorescence lifetime data from cells and/or colonies on a surface and the analysis of this data are controlled and performed in an automated and rapid manner using a computer. This screening method, or any imaging technique with suitable resolution, can then be used with either light-mediated patterned cell growth methodologies, as further provided by this invention, or mechanical methods to select individual cells or colonies based on their fluorescent properties. The invention further provides an automated method for selecting cells that exhibit desired characteristics. This method utilizes a computer-controlled scanning microscope system to focus a laser beam onto a surface upon which cells immobilized on the timescale of the procedure. The cells that are illuminated in this way are killed or their growth is inhibited. The focused laser beam is scanned across the surface and turned on and off during the scanning process such that only non-irradiated cells survive, resulting in a patterned growth of cells. In an alternative embodiment of this patterned growth cell selection method, a computer-controlled projection device, such as a micro-mirror array or a liquid crystal display system, is used to project an image onto the cells. Cells onto which this image is projected are killed or their growth is inhibited, again resulting in a patterned growth of cells. By employing this invention, cells can be selected with high spatial resolution, and large numbers of cells can be processed. This invention permits selection of desirable cells in directed evolution techniques, since cells can be selected with great resolution at sub-visual sizes, allowing a vast number of cells to be processed at once, without the need for antibiotic resistance markers or growth on selective media lacking required nutrients. Further, cell patterning can be used with essentially any cell type, including yeast and mammalian cells, using appropriately selected or modified chemical sensitizers.

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COMPUTER INTERFACED SCANNING FLUORESCENCE LIFETIME MICROSCOPE APPLIED TO DIRECTED EVOLUTION METHODOLOGIES AND METHODS FOR LIGHT-MEDIATED PATTERNING IN CELL SELECTION

CROSS-REFERENCE TO RELATED APPLICATIONS:

The present application claims priority to U.S. Provisional Application Serial Number 60/222,691, filed on August 2, 2000, inventors Neal T. Woodbury, Benjamin P. Bowen and Allan Scruggs, entitled Computer Interfaced Scanning Fluorescence Lifetime Microscope Applied to Directed Evolution Methodologies and Methods for Light-Mediated Patterning in Cell Selection, hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates generally to an apparatus and methods for rapidly and automatically screening and selecting cells exhibiting desirable physical traits and more specifically to a computer interfaced scanning fluorescence microscope applied to directed evolution methodologies and methods for light-mediated patterning in cell selection.

BACKGROUND OF THE INVENTION

Directed evolution is a process wherein the sequence of a gene is varied randomly by any of a number of methods, generating a library of mutated genes. These mutated genes are expressed and the functions of those gene products are assayed. A selection procedure is then applied to select those cells containing genes that express products with desirable functions. These cells, and their genes, are then selectively amplified, and the mutagenesis, screening and selection process is repeated until gene products with the most desirable functions are obtained.

The general scheme for directed evolution is shown in FIG. 1. First, variation is introduced into the gene in question by some type of random mutagenesis and a library of sequences is introduced into an organism (typically *Escherichia coli*) for expression of the altered proteins. Next, this population of bacteria is screened for the desired activity and individual colonies are selected. Finally, these selected bacteria are grown up (amplification of the selected genetic variants) and the plasmids expressing proteins with the most desirable functional traits are isolated. These then are used as heterogeneous templates for further random mutagenesis and reintroduced into the bacterium for another round of screening and amplification. This cycle is continued until the desired functional characteristics are achieved.

Directed evolution has been successfully used to generate new molecules with altered physical characteristics. For example, Doi et al. modified green fluorescent protein (GFP) to include a binding site for the TEM1-lactamase inhibitor and then used directed evolution

methods to produce a protein molecule whose fluorescent properties changed upon binding the target molecule. N. Doi and H. Yanagawa (1999) "Design of generic biosensors based on green fluorescent proteins with allosteric sites by directed evolution," *FEBS Letters* 453, 305-307). Directed evolution methodologies involving fluorescent proteins are particularly useful as fluorescence lends itself to sensitive and relatively easy, albeit slow, visual measurement.

GFP is one of a few different proteins that, in the absence of any externally supplied cofactor, fluoresce strongly in the visible region of the spectrum. Two of these proteins, GFP and a related red fluorescing protein (RFP) from reef corals, are commercially available in the form of expressible plasmids. Tsien, R.Y.(1998) "The Green Fluorescent Protein," *Annu. Rev. Biochem.* 67:509-544; Matz, V., et al. (1999) "Fluorescent proteins from nonbioluminescent Anthozoa species," *Nature Biotechnology* 17: 1969-1973. Functional transgenic expression of these fluorescent proteins is nearly universal in both eukaryotes and prokaryotes. Both the green and red fluorescing proteins have similar structural features, involving a beta-can fold structure enclosing a chromophore that is made via a reaction between 3 consecutive amino acids, serine, tyrosine and glycine. The quantum yield of fluorescence from the green fluorescent protein is near unity, while that from the red protein is apparently lower. Proteins with a variety of intermediate wavelengths have also been characterized.

Most of the directed evolution studies performed to date have utilized visual, qualitative screening of colonies on plates followed by manual selection of colonies that have enhanced activity in the protein of interest. Selection of cells may be based on a number of criteria, including color, morphology, size and fluorescence, depending on the protein of interest and the selectable marker chosen. When screening fluorescing cells, the process typically involves exciting cells with light and observing fluorescence from the genes or from molecules made by or associated with the genes in the cells. This visual screening process is slow and not particularly amenable to automation. As a result, the number of cells that can be screened and selected for further processing is greatly limited.

Although electronic cameras have been used to record fluorescence levels from colonies of cells, only the total relative yield of the fluorescence is recorded. This does not distinguish between fluorescence amplitude, which depends on both the photophysical properties of the fluorophore and its concentration, and fluorescence lifetime, which depends only on the photophysical properties of the fluorophore. Thus, directed evolution procedures that rely on steady state measurements of fluorescence select for changes that can be in either the amount of or the chemical properties of the fluorophore, but cannot specifically select for changes in molecular properties independent of concentration.

Also, while the use of electronic cameras has made it possible to screen cells more rapidly, its application has been limited by the ability to manually select cells exhibiting desired traits.

What is needed, therefore, is a more sensitive, higher resolution system that quantitates levels of fluorescence from microcolonies (colonies with a diameter of approximately 100 microns or less) or from individual cells, thus allowing cell screening on the order of millions of cells per round of directed evolution, coupled with an automated system for selecting the microcolonies or cells of interest.

Thus, the ability to perform directed evolution using a high resolution fluorescent assay that is sensitive, amenable to automation, and that distinguishes between fluorescence amplitude and fluorescence lifetime would be a significant asset for research as well as diagnostics and therapeutics.

SUMMARY OF THE INVENTION

This invention relates to a method for screening large numbers of individual cells or microcolonies based on fluorescence lifetime of fluorescent markers present in the cells. This invention involves:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the lifetime of the fluorescent light; and

correlating the lifetime of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light.

This invention further relates to a method for generating a high-resolution image map of cell fluorescence lifetime and using the image map to select cells exhibiting desired fluorescent properties.

This invention further relates to a method for automatically selecting cells exhibiting desired characteristics of imagable properties, such as fluorescence, color, morphology, or any other characteristic that may be detected and recorded, by selectively killing those cells not exhibiting the desired characteristics. In one embodiment, this involves:

providing a substrate with multiple locations, at least some of which contain one or more cells expressing an imagable property;

detecting and recording the imagable property;

identifying and recording locations containing cells expressing a desired characteristic of the imagable property and locations not containing cells expressing the desired characteristic of the imagable property; and

scanning lethal irradiation across the substrate through a high speed shutter and through

an objective, wherein the shutter is open only when the objective is positioned over locations not containing cells expressing the desired characteristic of the imagable property to thereby kill the cells in such locations.

In an alternative embodiment, the invention involves:

providing a substrate with multiple locations, at least some of which contain one or more cells expressing an imagable property;

detecting and recording the imagable property;

identifying and recording locations containing cells expressing a desired characteristic of the imagable property and locations not containing cells expressing the desired characteristic of the imagable property; and

projecting lethal irradiation only onto those locations not containing cells expressing the desired characteristic of the imagable property to thereby selectively kill those cells.

In both cases, light that is not in and of itself lethal can be used in place of lethal radiation if the cells are first treated with a sensitizing agent or are induced to synthesize endogenous sensitizing agents.

This invention further provides for an apparatus for the automated screening and selection of cells based on fluorescence properties.

This invention may be used with both prokaryotic and eukaryotic cells. This invention is useful in directed evolution methodologies but also may be used to screen and select cells in situ.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram illustrating the general process for directed evolution.

FIG. 2 is a schematic diagram of one embodiment of a fluorescence lifetime imaging system.

FIG. 3 is a schematic diagram of a four channel fluorescence lifetime imaging system.

FIG. 4 is a schematic diagram illustrating the use of a confocal microscope with a scanning stage to inspect and evaluate individual cells for fluorescence lifetimes and amplitudes, followed by selective killing of undesirable cells by an intense burst of ultraviolet light from an electro-optically shuttered argon laser.

FIG. 5 is a schematic diagram illustrating the use of a CCD camera to screen for fluorescence from cells and a digital light processor to specifically irradiate cells with ultraviolet light to kill individual cells that do not exhibit desired characteristics.

FIG. 6 is a flowchart summarizing the use of the computer interfaced scanning fluorescence microscope in directed evolution methodologies.

FIG. 7 is a flowchart summarizing the use of light mediated patterning in cell selection using imaging of lethal irradiation in directed evolution methodologies.

FIG. 8 is a graph illustrating time-correlated fluorescent signals from an individual *E. coli* cell expressing red fluorescent protein.

FIG. 9 is an illustration of one example of an optically patterned cell growth. FIG. 9A is a drawing of an image projected onto *E. coli* grown in the presence of a cationic porphyrin and plated onto an LB-plate, while FIG. 9B is a photograph of the pattern of cell growth resulting after the plate is exposed to visible light.

DETAILED DESCRIPTION OF THE INVENTION

This invention provides a method for screening large numbers of individual cells or colonies of cells using scanning microscopy coupled with fluorescence lifetime measurement and analysis, using time-correlated single photon counting. Both the imaging of the fluorescence lifetime data from cells and/or colonies on a surface and the analysis of this data are controlled and performed in an automated and rapid manner using a computer. This screening method can then be used with either light-mediated patterned cell growth methodologies, as further provided by this invention, or mechanical methods to select individual cells or colonies based on their fluorescent properties.

This invention provides two distinct improvements over current methods for screening cells. First, automated scanning of the fluorescent properties of cells or colonies enables a large number of colonies to be screened rapidly and automatically. In the practice of this invention, a slide containing millions of cells can be examined in minutes. Second, the method allows one to determine independently the lifetime and the amplitude of the fluorescence. Current methods of screening involve either a manual or automated survey of total fluorescence, which depends on both the lifetime and the amplitude of the fluorescence. By distinguishing between lifetime and amplitude, one can determine whether changes in fluorescence are due in changes in numbers of fluorophores or changes in the excited state lifetime (i.e., the chemical properties) of the fluorophores.

The invention further provides an automated method for selecting cells that exhibit desired characteristics. In one embodiment, this method utilizes a computer-controlled scanning microscope system to focus a laser beam onto a surface upon which cells immobilized on the timescale of the procedure. The cells that are illuminated in this way are killed or their growth is inhibited. The focused laser beam is scanned across the surface and turned on and off during the scanning process such that only non-irradiated cells survive, resulting in a patterned growth of cells. Alternatively, other scanning systems, such as acousto-optical scanners, scanning mirror systems, or other scanning systems known in the art can be used.

In an alternative embodiment of this patterned growth cell selection method, a computer-controlled projection device, such as a micro-mirror array or a liquid crystal display system, is used to project an image onto the cells. Cells onto which this image is projected are killed or their growth is inhibited, again resulting in a patterned growth of cells. As used herein, projection can be accomplished by directing a specific image onto a substrate, by providing a mask to thereby cover portions of the substrate not to be irradiated, or by other methods known in the art.

In both embodiments, inhibition of cell growth occurs either by the use of light wavelengths that are themselves lethal to the cells, such as ultraviolet light, or via the use sensitizing chemicals that absorb light at particular wavelengths and generate lethal damage to the cell.

By employing this invention, cells can be selected with high spatial resolution, and large numbers of cells can be processed. Importantly, this cell selection can be done strictly based on function, as manifested in some detectable property of the cell such as fluorescence or absorbance. This is in contrast with other high throughput selection procedures that utilize large numbers of cells, but require that the selected trait confer a significant growth advantage. This process is preferably coupled with high throughput imaging of cell fluorescence using either a sensitive charge couple device based camera (CCD) camera or a scanning microscope.

This invention permits selection of desirable cells in directed evolution techniques, since cells can be selected with great resolution at sub-visual sizes, allowing a vast number of cells to be processed at once, without the need for antibiotic resistance markers or growth on selective media lacking required nutrients. This invention can also be used in color-based assays for transformation of bacterial cells with plasmid DNA, obviating the need for antibiotic resistance. Further, cell patterning can be used with essentially any cell type, including yeast and mammalian cells, using appropriately selected or modified chemical sensitizers.

Spatially Imaged Fluorescence Lifetime Detection Device

The spatially imaged fluorescence lifetime detection device comprises a scanning microscope system with a nanopositioning or micropositioning stage, or a laser scanning system, modified by the inclusion of a pulsed excitation source, a photon counting detector and appropriate time correlation electronics. In one embodiment, a confocal microscope is used, although other microscope systems may also be used. The positioning capability can be in either two or three dimensions, and allows computer controlled movement system that can position the focal point of a beam on a sample with submicron accuracy. Such positioning stages or scanning systems are commercially available from, for example, Mad City Labs (Madison, Wisconsin; Nanoh100-xy), PI (Physics Instruments, Germany) or Brimrose Corporation of America

(Baltimore, Maryland). Alternatively, the stage may be kept stationary while the beam is moved relative to the stage.

The pulsed excitation source can be any laser or light source with a high repetition rate and a short pulse width, generating pulses at greater than 10 kHz. In one embodiment, an actively mode-locked NdYAG laser is used, generating pulses at 80 MHz, which, after compression, are 5 ps in duration. The wavelength used to excite the sample varies according to the sample. In another specific embodiment, an ultrafast titanium sapphire oscillator is used, pumped by a continuous laser source such as a diode-pumped NdYAG laser. The oscillator produces pulses of about 100 femtosecond duration at a repetition rate of 80 MHz.

The photon counting device may be any detector capable of detecting and counting photons, generating electrical pulses for each photon detected. In one embodiment, an avalanche photodiode is used. Alternatively, a photomultiplier tube is employed. Such devices are well known in the art.

The time correlation electronics is any device that can receive information both from the photon counting device and from the laser, or from a fast photodiode associated with the laser, and record time in two dimensions. Preferably, the device uses time correlated single photon counting (TCSPC) to determine the time between a laser pulse and the resulting photon emission (i.e., the excited state lifetime of the molecule giving rise to the photon, generally in the nanoseconds time frame) and it records the time at which the photon arrives, in the lab time frame, typically with microsecond to millisecond accuracy. Such time correlation electronics are commercially available from, for example, Becker & Hickl (Berlin, Germany) or PicoQuant (Berlin, Germany).

In the practice of the invention, a beam from the high repetition rate pulsed laser is passed into the microscope, reflected from a dichroic mirror, and used to excite a sample. Preferably, the sample sits on a 3-D translation/positioning stage or the laser position is controlled by a scanning device such as a rotating mirror or an acousto-optic scanner (these devices will be collectively referred to as "positioners") and its position relative to the focused laser beam is controlled by the computer, thus allowing scanning of the sample. The sample consists of single cells or colonies of cells sitting on, or embedded in, a solid substrate so that their positions do not vary over the period of time required to obtain the image. The cells may be either prokaryotic or eukaryotic, with at least some portion of the cells exhibiting fluorescence, or other imagable property, when excited.

Upon excitation, the sample emits a fluorescent signal that passes through various optical elements. In one embodiment, the fluorescence passes through the dichroic mirror, as the fluorescence is at a wavelength that is not reflected by the dichroic mirror. Each photon emitted

by the sample is counted at the detector and the time of arrival of each emitted photon relative to the laser pulse is correlated, stored and analyzed on the computer.

FIG. 2 shows one embodiment of the spatially imaged fluorescence lifetime detection system 10. A high frequency (greater than 10 kHz) pulsed laser system 12 is used as the excitation source. The laser emits a light beam 14, which is directed via the use of a mirror 16 to a dichroic mirror 18. The laser is connected to a 2-D TCSPC board 20, which receives an input from the laser that marks the time at which the laser pulse was initiated.

The dichroic mirror 18 reflects the laser light beam 14 into the microscope system 22, where it is directed via additional mirror(s) 24 to the objective lens 26. This lens system focuses the beam onto the sample 28. The sample is attached to a computer-controlled positioning stage 30.

The laser beam excites molecules within at least some of the cells on the stage, causing them to emit light as fluorescence. Some of this fluorescence 32 is captured by the objective lens 26 and passed back into the microscope along the same path through which the laser light beam 14 entered. The fluorescence is reflected from mirror 24 to the dichroic mirror 18, where the fluorescent light passes through, as the dichroic mirror is selected to reflect light at the wavelength of the laser light beam but transmit light at the wavelength of the fluorescent light. The fluorescent light 32 then passes through a filter 34 to remove any remaining laser light while efficiently passing light in the wavelength region of the fluorescence and, optionally, through a confocal pinhole 36 (typically on the order of 50 to 150 microns in diameter and translatable along the axis of the laser beam) to better define the volume of sample being probed.

The fluorescent light is detected by an avalanche photodiode 38, which generates electrical pulses for each photon of fluorescent light it detects. These pulses are transmitted to the TCSPC board 20. The TCSPC board records the time at which the photon arrived and uses time correlated single photon counting to determine the time between the laser pulse and the photon emission. This information is transmitted to a computer 40, where it is stored and analyzed. Optionally, computer 40 is interfaced with the positioning stage 30.

An alternative embodiment of the spatially imaged fluorescence lifetime detection device is shown in FIG. 3. In this embodiment, a four channel system records not only the excited state lifetime of each fluorophore that gives rise to each photon detected, but also records the polarization of the photon and wavelength region in which it was emitted. This additional information can also be used to determine which cells or colonies exhibit the most desirable characteristics; for example, those cells containing the most desirable gene products in the directed evolution process.

In this embodiment, the pulsed laser 42 emits a light beam 44, which is directed via the use of a mirror 46 to a dichroic mirror 48. The laser is connected to a 2-D TCSPC board 50, which receives an input from the laser that marks the time at which the laser pulse was initiated.

The dichroic mirror 48 reflects the laser light beam 44 into the microscope system 52, where it is directed via additional mirror(s) 54 to the objective lens 56. This lens system focuses the light beam onto the sample 58. The sample is attached to a 2-D positioning stage 60 controlled by a computer (not shown).

As the laser beam excites molecules within at least some of the cells on the stage, fluorescent light 62 is emitted, some of which is captured by the objective lens 56 and passed back into the microscope along the same path through which the laser light beam 44 entered. Upon reaching the dichroic mirror 48, the fluorescent light passes through the dichroic mirror, through a filter 63 and, optionally, through a confocal pinhole 64.

The fluorescent light then enters a polarizer 66, emerging from the polarizer in two perpendicular planes 68, 70 as polarized light, each of which enters a wavelength separator 72, 74. Polarized light passing through the wavelength separator is again split into two paths of light, each of which is detected by an avalanche photodiode 76, 78, 80, 82. The avalanche photodiode generates electrical pulses for each photon of fluorescent light it detects. These pulses are transmitted through multiplexing electronics 84 to the TCSPC board 50. The multiplexing electronics comprise a circuit which adds a different period of delay time to the pulses arriving from different channels (Becker & Hickl, Berlin, Germany). In this way the TCSPC board is able to differentiate between the signals from the four different detectors. The TCSPC board records the wavelength region and polarization of each photon, in addition to the lifetime of the excited state that gave rise to the photon. These attributes are all be recorded along with the arrival time of each photon in the lab time frame with a millisecond resolution. This information is transmitted to a computer 86, where it is stored and analyzed.

In the embodiments illustrated in figures 2 and 3, a scanning fluorescent microscope is used to image the fluorescence from cells, which is then used to determine which regions of the surface are to be illuminated with lethal irradiation. Various other methods for imaging cells can also be used. For example, a charge couple device based camera (CCD camera) may be used. It is also possible to monitor absorbance in a spatially resolved fashion or to use a scanning probe microscope to generate an image of the morphology, electrical characteristics, surface properties, etc., of cells. Any imaging system with sufficient spatial resolution to resolve the features important in identifying cells with desired properties may be employed.

Light Mediated Patterning in Cell Selection

The lifetime image determined by correlating the excited state lifetime measured by the spatially imaged fluorescence lifetime detection system with the position of the positioner at the time of the measurement within the lab time frame can be used to determine which of the cells or colonies in the sample have the desired characteristics. Then, any of several computer-controlled methods for rapidly selecting individual cells or colonies can be employed to either remove specifically the cells of interest (positive selection) or to kill cells that do not have the desired qualities (negative selection). For example, any of several automated mechanical methods for picking cell colonies and moving them to a clean substrate can be used. Whatever selection method is used, the lifetime image of the cells or colonies is stored on a computer and the computer can be then used to automatically decide which cells should be selected, using this information to initiate an automated procedure for cell selection.

The present invention provides methods for selecting cells based on patterned cell growth. This method employs a negative selection strategy, in which cells identified not to exhibit the desired characteristic are selectively killed using a scanning laser. Alternatively, a light "image" is projected onto the sample that kills the unwanted cells.

In one embodiment, fluorescence from cells on a surface is recorded by a scanning fluorescence microscope capable of recording both the fluorescence amplitude and its lifetime, via the use of single photon counting technology, as described above. The image thus obtained of the fluorescence on the surface is used to determine which cells or colonies exhibit the desired fluorescence characteristics. This information is processed and a new image (the "kill image") is generated by the computer. This kill image is designed to irradiate the undesirable cells (that is, those not exhibiting the desired fluorescence characteristics) under conditions that are lethal to those cells, leaving the cells with desirable fluorescence properties to continue growing. The kill image is projected by scanning a UV laser across the surface of the plate, using a fast shutter (typically an acousto-optic modulator) to determine at what positions lethal irradiation occurs. One UV laser suitable for use in this invention is an argon ion laser.

FIG. 4 shows an example of the use of a UV laser with a scanning fluorescence microscope to select cells based on their fluorescent properties. In FIG. 4, a mode-locked pulsed laser system 88 is used as an excitation source. The laser emits a light beam 90, which is directed to a dichroic mirror 92. The laser is connected to a 2-D TCSPC board (not shown), which receives an input from the laser that marks the time at which the laser pulse was initiated.

The light beam is reflected into a microscope system by the dichroic mirror 92, into the objective lens 94. This lens system focuses the light beam onto a sample of cells located on the surface of a plate 96 positioned on a translation or positioning stage 98, causing some portion of the cells to emit fluorescent light 100. Some of this fluorescence is captured by the objective

lens and passed back into the microscope along the same path through which the laser light entered. Upon reaching the dichroic mirror 92, the fluorescence passes through as the dichroic mirror is designed to reflect light at the wavelength of the laser but transmit light at the wavelength of the fluorescence. Optionally, the fluorescence is then passed through a collimating lens 102 and a confocal pinhole (not shown).

The cell fluorescence is imaged by scanning the stage, detecting the fluorescence with a detection system 104, as shown in detail in FIG. 2, and recording both the amplitude and the lifetime of the emission at each point using time correlated single photon counting techniques. The image thus generated is stored and analyzed in a computer (not shown) and used to determine which cells or colonies on the surface should receive lethal irradiation from the UV laser 106. A computer controls both the position of the stage 98 and the shutter 108 in conjunction, such that UV light 110 from the UV laser is directed via mirrors 92, 112 to the sample, specifically irradiating the undesirable cells with UV light, thus killing them. In this figure, mirror 112 is a dichroic mirror that reflects UV light, while transmitting light at the wavelength of the pulsed laser. Other configurations are possible. Importantly, the divergence properties of the UV laser are optimized so that its focal point is in the same position along the axis perpendicular to the sample surface as the longer wavelength measuring beam is.

It is also possible to use a visible laser beam in conjunction with the scanning laser approach to patterning cell growth if the cells are first sensitized to visible light by any of a number of means described below. This has the advantage that the same laser that is used to monitor the fluorescence from the cells can be used to kill the cells simply by increasing the light intensity to a lethal level.

It is also possible to use an ultrafast laser pulse (on the order of a few hundred femtosecond duration) as both the excitation source for performing the time correlated single photon counting measurements of excited state lifetimes and as the source of light to directly kill the unwanted cells even without the use of sensitizers. Both processes can be performed by multiphoton excitation. The very high peak intensity of short pulses make it possible for the fluorophore, such as GFP, to absorb two photons of near infrared light and then to fluoresce in the usual visible region.

This has several advantages. First, since the excitation is in the near infrared, it is very well separated spectrally from the fluorescence. This decreases the background due to scattering of various kinds as well as other fluorescent materials. Second, because the process depends on multiple photons, the volume of material where the photon density is high enough to cause the multiphoton absorption is smaller, increasing the spatial resolution of the technique. Finally, by using near infrared or even infrared light as the source of photons for the multiphoton excitation, it is possible to excite fluorophore in cells below of surface of a sample allowing three

dimensional mapping of the fluorescence, as long wavelength light will penetrate more deeply than visible or UV light. This deep probing occurs without exciting fluorophore in the cells above, because the intensity of light will only be great enough as the focal point of the beam to perform the multiphoton excitation.

The same procedure can be used to kill cells by producing the same transitions in DNA and protein molecules that make UV light absorption lethal, by using multiple photons of longer wavelength light. This can be done effectively by simply increasing the intensity of the laser beam when focused on the cell or cells to be killed. Multiple photons will then excite the same transitions in DNA and protein that UV light does and kill the cells. The great advantage here is that a single beam of light can be used both to probe and to kill the cells. As noted above for multiphoton excitation of fluorescence, multiphoton excitation of bactericidal transitions in DNA and protein molecules in the cell can be performed with higher spatial resolution that can be done with UV light. In addition, the near infrared or infrared laser pulses can penetrate the surface allowing for three dimensional killing of cells. Because the unfocused light does not have the intensity to cause multiphoton excitation of lethal transitions, the killing will only occur at the focal point of the laser and not in the cells above.

The intensity and wavelength of the laser beam used for multiphoton excitation screening and cell selection depends both on the specific fluorophores being used and on the geometric constraints of the sample. The wavelength used for screening need be a multiple of the absorbance wavelength preferred for the fluorophore to be excited. The power level of the laser is also dependent on the nature of the fluorophore, the concentration of the fluorophore and the size of the region to be excited at any given time. Generally, the minimum laser intensity required to obtain a substantial signal from the fluorophore should be used, and this can be determined by performing test scans with increasing light levels. For killing cells in particular patterns, the wavelength and intensity depends on the mechanism of killing employed. For example, if a specific sensitizer is used, the wavelength of the laser need be a multiple of the absorbance wavelength of the sensitizer. The appropriate power again be determined by increasing the laser in test scans until cell death is regularly achieved. If no sensitizer is used, multiphoton excitation of DNA and/or protein molecules in the cell are possible by picking an excitation wavelength that is a multiple of a wavelength in the absorbance range of these molecules (190 - 290 nm). The intensity required will depend on the multiphoton absorption cross section and the cell type. Again this can be determined empirically by increasing the intensity in a test case until high resolution cell death is achieved. Multiphoton beams have previously been used for "nanosurgery" at the subcellular level (Konig, 2000, J. of Microscopy, vol. 200, 83-104).

In an alternative method of light mediated patterning in cell selection, fluorescence from cells on a surface is recorded by a CCD camera. The image of the fluorescence on the surface is used to determine which cells or colonies contain the desired fluorescence characteristics (i.e., which cells are expressing biomolecules that have the desired traits). This information is processed and a kill image is generated by the computer. This image is designed to irradiate the cells that are undesirable under conditions which will prove lethal to those cells and leave the cells with desirable fluorescence properties to continue growing. In one embodiment, the kill image is the inverse of the fluorescence image. Thus, when the kill image is projected onto the cells, the cells with the highest fluorescence receive the least radiation (and thus continue growing) while cells with the lowest fluorescence receive the greatest dose of radiation (and are thus killed). Alternatively, the new image can be designed to irradiate all cells with fluorescent activity below a pre-determined threshold. Other kill image configurations are apparent.

The kill image is projected using a computer-controlled imaging system such as micro-mirror array chips (digital light processors or DLPs) or liquid crystal projection units that are commonly used for projecting computer generated images on screens (available from Texas Instruments, Dallas, Texas or InFocus Corporation, Wilsonville, Oregon). These projection systems must be significantly modified for this purpose. The lamp is selected to emit light at a wavelength or range of wavelengths suitable for killing selected cells. Also, the imaging optics must be selected both to be appropriate for the size of the image to be generated and for the wavelength region of light used. Finally, appropriate filters must be used to select the desired wavelength regions of light. In particular, a high quality lens system with low optical aberrations is used such that the inherent resolution of the instrument is maintained when the image is reduced to the size of the target.

In one embodiment, the computer storing the kill image is connected to an InFocus® model projector, which uses the video output from a computer to display an image onto a screen (InFocus Corporation, Wilsonville, Oregon). The focal optics of the projector are replaced by a 50mm Nikon® lens area, so that the output can be focused on the cells with image features having the proper size and alignment (Nikon, Inc., New York, New York). Other lens systems can also be used, depending on the size of the target area. The projector uses an aluminum micro-mirror array that is electronically controlled. Suitable chip dimensions are 1024 x 786 pixels, although other dimensions may be used depending on the desired resolution. When focused on an agar plate containing cells, the image size is approximately 11 cm by 8.5 cm, producing a pixel size of approximately 0.07 mm/pixel. Such an optical arrangement allows selective imaging and killing in a library of 100 micron colonies containing several hundred thousand members.

FIG. 5 shows a CCD camera being used to image the fluorescence from cells. This information is then used by the computer to generate the kill image of lethal irradiation projected onto the plate of bacteria. In this embodiment, the cells to be screened and selected are grown in a plate 114 on agar or other solid substrate, preferably which supports growth of the cells. The plate is supported on a transilluminator 116, with a filter 118 between the plate and the transilluminator. The filter 118 is selected to permit a wavelength or wavelengths of light suitable for exciting fluorescence of the cells to pass from the transilluminator 116 to the cells on the plate 114, but not wavelengths that would interfere with the detection of fluorescence from the cells.

Fluorescence 120 emitted from the excited cells is reflected from a mirror 122, through a filter 124 and a lens 126 into a CCD camera 128. The fluorescence image detected by the CCD camera is stored in a computer (not shown) and is used to generate the kill image designed to selectively kill cells not exhibiting the desired traits. An ultraviolet light source 130 emits UV light 132 into a digital light processor 134, which projects the UV light image through a lens 136 and onto a dichroic mirror 138, selected to allow the fluorescence used for imaging by the CCD camera to pass through and UV light to be reflected. The dichroic mirror 138 reflects the UV light image onto the cells in the plate 114, selectively killing some portion of the cells.

Various other methods for imaging cells could also be used. Alternatively, one could use a scanning fluorescence microscope (one example is a scanning microscope capable of determining the lifetime of the fluorescence, its polarization and its wavelength region, as is discussed above with reference to FIG. 3). It is also possible to monitor absorbance in a spatially resolved fashion or to use a scanning probe microscope to generate an image of the morphology, electrical characteristics, surface properties, etc. of cells. Any imaging system that works with high enough spatial resolution to resolve the features important in determining which cells have the most advantageous properties for the directed evolution project of interest would work.

Both of the above embodiments of a system for automated cell selection use UV light as the source of lethal irradiation. The use of UV light is both a simple and an efficient means to kill cells. However, alternative methods using visible or near infrared light sources are also available. When using visible or near infrared light, a sensitizing agent is first applied to the cells that will absorb the light, using the light energy to either directly damage the cell or to generate a chemical species that damages the cells. Alternatively, cells may be chemically induced to produce endogenous photosensitizers.

One example of a sensitizing agent is an intercalating or DNA binding dye, such as ethidium bromide, thiazole orange, etc. These dyes associate directly with DNA and, upon light absorption, can cut or damage the cell DNA, causing cell death. Alternatively, singlet oxygen generating molecules, such as porphyrins, certain cyanine dyes and the like may be used. In their

excited state, these molecules can interact with molecular oxygen (normally in a triplet form) to generate the highly reactive singlet oxygen species. Singlet oxygen reacts with most organic compounds, often destroying their normal function in the process. If enough damage is done, the cell dies.

Porphyrins are strong absorbers of visible light, and many form long lived triplet states upon excitation with visible light. Since the amount of damage done to the cells depends on the amount of light absorbed by porphyrins in the cell, which, in turn, is a function of the amount of porphyrin in the cell and the amount of incident light, cells in relatively dark areas have a much higher chance of survival than cells in relatively bright areas of the image. The more porphyrin there is in a cell, and the more light incident on that area of the plate, the more damage will be done, and thus the chance of cell survival will be less.

For gram-negative bacteria, cationic porphyrins have been found to be the most efficient exogenous porphyrin photosensitizers. Chemical sensitizers for a large variety of cell types, including eukaryotic cells, are well known in the art. For example, several chemical photosensitizers are described in the photodynamic therapy literature, in which chemicals that are taken up more rapidly by cancer cells or by pathogens relative to normal cells are used to sensitize these cells to destruction by light.

Two chemical sensitizers effective for use with *E. coli*, a gram negative bacteria, are tetra(4N-methylpyridyl) porphine and tetra(4N, N,N-trimethyl-anilinium) porphine. Greater than 99.99% of *E. coli* cells are killed by incubation with these porphyrins at 10 ug/mL for 5 minutes, followed by irradiation at 6mW/cm^2 for 20 minutes. By contrast, the anionic porphyrin tetra (4–sulphonatophenyl) porphine shows no photoinactivation under the same conditions. Merchat et al. (1996) *Journal of Photochemistry and Photobiology B: Biology* 32: 153-157.

Alternatively, *E. coli* can be induced to synthesize endogenous porphyrins precursors by incubating the cells with d-aminolaevulinic acid at 5-9 mM for 15 minutes. Szocs, et al. (1999) *Journal of Photochemistry and Photobiology B: Biology* 50: 8-17. Following induction, 99.4% inactivation of *E. coli* is seen after 90 minutes of irradiation at 0.08 W/cm^2.

Use of Computer Interfaced Scanning Fluorescence Microscope in Cell Screening and Selection in Directed Evolution Methodologies

As is apparent from the above discussion, the computer interfaced scanning fluorescence microscope is useful in directed evolution methodologies where fluorescence, or other imagable characteristic, is used as an indicator of protein function to screen and select cells for desired functional characteristics. An overview of this method is shown in FIG. 6.

First, the sample of the cells to be screened is placed on a positioning stage and positioned under the objective of the computer-interfaced scanning microscope. The computer moves the positioning stage, recording the position of the stage relative to the objective in lab frame. At the same time, the cells are excited by a light source, such as a mode-locked laser, through the objective of the scanning microscope. Some portion of the resulting cell fluorescence passes through the objective and is directed to an avalanche photodiode or photomultiplier tube, interfaced with a 2-D TCSPC board and a computer, where the fluorescence lifetime and amplitude and is measured and recorded. The computer is also interfaced with the laser or other light source and records and stores the time at which each laser pulse is initiated.

The fluorescence data is correlated with the position of the positioning stage (and thus the position of the sample), generating a high-resolution image map of individual cell (or microcolony) positions based on the fluorescence lifetime and amplitude data.

This high-resolution map image is stored for use in identifying individual cells or microcolonies expressing desirable functional traits, as measured by fluorescence lifetime and amplitude. These cells or microcolonies are then selected for future rounds of directed evolution.

Alternatively, the high-resolution map is used to generate a high-resolution kill image map of cells or colonies not expressing desirable functional traits, as measured by fluorescence data. Using this kill image map, a UV laser is directed through a fast shutter and into the objective of the scanning microscope, where it is scanned across the sample of cells. Both the shutter and the nanopositioning stage are controlled by the computer such that the shutter is open when undesirable cells or microcolonies are positioned under the objective, killing those cells, while the shutter is closed when desirable cells or microcolonies are positioned under the objective.

As is apparent, this method selectively and automatically kills undesirable cells (or microcolonies) one cell (or microcolony) at a time, greatly increasing the number of cells which can be screened and selected during directed evolution.

Use of Light Mediated Patterning Using Imaging of Lethal Irradiation in Directed Evolution Methodologies

FIG. 7 shows an overview of the use of light mediated patterning using imaging of lethal irradiation in directed evolution methodologies where fluorescence, or other imagable characteristic, is used as an indicator of protein function, cell morphology or activity of cellular components. In this method, a high resolution kill map is projected onto a sample, selectively killing large populations of undesirable cells while permitting desirable cells to continue growing.

First, a sample of cells to be screened for fluorescence is excited by a light source such as a transilluminator, causing some portion of the cells to fluoresce. This fluorescence is detected

and recorded by an electronic camera, such as a CCD camera, interfaced with a computer. The fluorescence data is used to create a high-resolution map correlating fluorescence with cell (or microcolony) position within the sample.

Next, the fluorescence image is used to generate a high-resolution kill map of cells (or microcolonies) not expressing desirable functional characteristics. Lethal irradiation, such as UV light, is projected onto the sample in the form of the kill image. Alternatively, the sample is first treated with a photosensitizer, or endogenous photosensitizers are induced, and a wavelength of light absorbed by the photosensitizer is projected onto the cells in the form of the kill image. The projection of the kill image may be controlled by a digital light processor interfaced with the computer storing the kill image. In any case, the irradiation selectively kills the cells on which the kill image falls, leaving the nonirradiated cells to continue growing.

Because the kill image is a high resolution map based on fluorescence data correlated to desirable functional characteristics, this method of light mediated patterning is a rapid and efficient way to simultaneously select large numbers of cells or microcolonies for further directed evolution studies.

As is apparent, the detection technique used to generate the high resolution map may by varied depending on the imagable property of interest. So long as the property of interest, whether it is cell morphology, colorimetric reactions or the like, can be imaged, a high resolution map can be generated for use in patterned cell selection as described for fluorescing cells.

The cell screening and selection methods described above are not limited to use with bacterial cells. The methodologies of this invention have potential applications for eukaryotic cells as well. For example, patterned cell selection can be used for the selection of yeast cells, which are often used in various techniques in which libraries of gene sequences are generated and specific colonies are selected. Patterned cell selection could also be used in the selection of mammalian cells for similar reasons.

In addition, patterned cell selection could have direct application in the field of photodynamic therapy presently used for treatment of certain types of cancer. Porphyrins selectively accumulate in certain types of cancer cells, causing the cancer cells to fluoresce. Presently, light is used to illuminate all cells in the vicinity of the cancer cells. The cancer cells, due to their higher concentration of porphyrin, are killed faster than the normal cells, but many normal cells die as well.

By using the fluorescence from the porphyrin or from a specific binding fluorophore in the cancer cells to map the growth of the cancer cells on a two dimensional surface, such as the skin, lining of the gut, surface of an organ, etc., and selectively illuminating only the cancer cells, and not the healthy cells, much more complete killing of the cancer could be achieved without harming the healthy cells.

Moreover, because multiphoton excitation permits deep probing and scanning of the cells in three dimensions, it has important implications for medical treatments where it is desirable to specifically target and kill some cells while leaving others intact beyond a two dimensional surface. For example, the multiphoton excitation technique can be used to first screen tumor sites in a patient, using a three dimensional laser scanning methodology (Konig, Journal of Microscopy, Vol. 200, part 2, November 2000, pp. 83 -104, hereby incorporated by reference in its entirety). It can then be used to kill selectively cancer cells while leaving noncancer cells intact. Similarly, many types of benign skin disorders or cosmetic manipulations, such as the removal of hair cells, could be treated using multiphoton excitation screening and selection.

Example 1: Time Correlated Fluorescent Signals from Individual E. coli Expressing Red Fluorescent Protein.

FIG. 8 shows time correlated data taken on a single cell of *E. coli* expressing red fluorescent protein (RFP) from the dsRED plasmid, available commercially from ClonTech Laboratories, Inc. (Palo Alto, California). The trace was taken using an apparatus similar to the one shown in FIG. 2, but using a sample suspended in solution rather than on a solid substrate.

Specifically, a frequency doubled, pulse compressed, and mode locked Nd:YAG laser (532 nm, 10 psec) was used to excite the sample at a repetition rate of 82 MHz. To ensure proper beam quality and polarization, the light was passed through a single mode, polarization preserving glass fiber (F-SPA, Newport, Irvine, CA) and a polarizing beam splitter (05BC15PH.3, Newport, Irvine, CA). The laser light was delivered into an inverted, confocal microscope and reflected up towards the microscope objective with a dichroic mirror (Q570LP, Omega Optical, Brattleboro, VT).

The sample, a 50 microliter droplet containing *E. coli* cells expressing the plasmid dsRED to produce red fluorescent protein, was spread onto a glass cover slip (22x50mm No 1.5, VWR, West Chester, PA). The same objective (100x PlanApo 1.4NA, Olympus, Tokyo Japan) used to focus the laser also collected the fluorescence.

The collected fluorescence passed through the dichroic mirror and was focused onto a 50 micron diameter pinhole (910-PH50, Newport, Irvine, CA). The fluorescence was then split by a polarizing beam splitter (05FC16PB.3, Newport, Irvine, CA), sending photons polarized parallel to the laser to detector one and photons polarized perpendicular to the laser to detector two (Perkin Elmer, SPCM-AQR-12, Canada).

To remove Raleigh and Raman scattering, the fluorescence was passed through a custom emission filter (Omega Optical, Brattleboro, VT). The filter specifically blocks 532 nm light and the water Raman scattering from 532 nm light. The signal from the detectors and a synchronization signal from each laser pulse were sent into an in-house designed and built signal

multiplexor / router. The multiplexor sends a start signal and a stop signal into the Timeharp TCSCP board (PicoQuant, Berlin, Germany). The multiplexor also separates the signals from multiple detectors in regions of time defined by the repetition rate of the laser. Each detector's signal occupies a 12 ns region of time.

The resulting time-correlated fluorescent signals from an individual E. coli expressing RFP are shown in FIG. 8.

Example 2: Light-Mediated Patterning in Cell Selection.

The cationic porphyrin 5,10,15,20-Tetrakis [4-(trimethylammonio) phenyl]-21H,23H-porphine (TmaP), which has a maximum absorption at 412 nm wavelength, was added to a 3 mL liquid culture of *E. coli* in Luria Broth (LB) and the culture was incubated in the dark overnight. Approximately 50uL of the culture was plated on an LB/TmaP agar plate, and portions of the plate was irradiated for about 2 minutes with visible light passed through a blue filter. The cells were then placed in an incubator and allowed to grow overnight at 37° C.

The image projected onto the plate is shown in FIG. 9A. As shown in FIG. 9B, those portions of the plate receiving visible light (the "white" portion of the image shown in FIG. 9A) show little or no growth of *E. coli*, while portions of the plate receiving little or no visible light (the "black" portion of the image shown in FIG. 9A) show high density growth in the form of the Arizona State University mascot, the Sun Devil "Sparky."

It is emphasized at this point that the present invention is not intended to be limited to the exemplary embodiments shown and described above. The preceding merely illustrates the principles of the invention. It will be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples and conditional language recited herein are principally intended expressly to be only for pedagogical purposes and to aid the reader in understanding the principles of the invention and the concepts contributed by the inventors to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Morever, all statements herein reciting principles, aspects, and embodiments of the invention as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents and equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure. The scope of the present invention, therefore, is not intended to be limited to the exemplary embodiments shown and described herein. Rather, the scope and spirit of present invention is embodied by the appended claims.

WHAT IS CLAIMED IS:

1. An automated method for analyzing cells containing fluorescent markers, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the lifetime of the fluorescent light; and

correlating the lifetime of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light.

2. The method of claim 1, further comprising the step of generating an image map of the substrate, the image map indicating those locations emitting fluorescent light with a desired lifetime.

3. The method of claim 1, wherein the light beam is directed onto each location through an objective of a scanning microscope.

4. The method of claim 1, wherein the light beam is generated by a high frequency pulsed laser.

5. The method of claim 1, wherein the fluorescent light is detected by an avalanche photodiode.

6. The method of claim 1, wherein the lifetime of the fluorescent light is measured by a computer-interfaced time correlated single photon counting board.

7. A method for imaging and analyzing fluorescence lifetime in cells, the method comprising the steps of:

providing a sample of cells, the cells containing a fluorescent marker, wherein the sample is disposed on a positioning stage;

scanning a light beam across the sample of cells through an objective of a scanning microscope, causing the cells to emit fluorescent light;

detecting the fluorescent light emitted by the cells;

measuring the lifetime of the fluorescent light;

correlating the lifetime of the fluorescent light with the position of objective relative to the sample to thereby generate a high-resolution image map of cell fluorescence lifetime; and

storing the high resolution image map.

8. A method for imaging and analyzing fluorescence lifetime and anisotropy in cells, the method comprising the steps of:

providing a sample of cells, the cells containing a fluorescent marker, wherein the sample is disposed on a positioning stage;

scanning a light beam across the sample of cells through an objective of a scanning microscope, causing the cells to emit fluorescent light;

passing the fluorescent light through a polarizer, to thereby produce two perpendicular planes of polarized light;

passing each plane of polarized light through a wavelength separator, to thereby produce four fluorescent signals;

independently detecting each fluorescent signal; and

measuring and recording the lifetime, wavelength region and polarization of each fluorescent signal.

9. The method of claim 8, further comprising the step of correlating the lifetime, wavelength region and polarization of each fluorescent signal with the position of objective relative to the sample to thereby generate a high-resolution image map of cell fluorescence lifetime, wavelength region and polarization.

10. An apparatus for detecting spatially imaged fluorescence lifetime, comprising:

a high frequency pulsed laser;

a light detector;

a time correlated single photon counting board, the board interfaced with the laser and with the light detector; and

a computer, the computer interfaced with the time correlated single photon counting board;

wherein the laser emits radiation onto a sample thereby causing the sample to emit fluorescent light, the fluorescent light being sensed by the light detector thereby causing the light detector to generate electrical pulses, the electrical pulses being sensed by the time correlated single photon counting board to thereby measure the lifetime of the fluorescent light emitted by

the sample, and the lifetime of the fluorescent light emitted by the sample being stored in the computer.

11. A computer interfaced scanning microscope system for detecting spatially imaged fluorescence lifetime, the system comprising:

a high frequency pulsed laser;

an objective lens;

a positioner located adjacent to the objective lens, the positioner including a stage designed to hold a sample, the positioner designed to move the stage relative to the objective lens to thereby variably position the sample relative to the focal point of the objective lens, and the positioner further designed to sense and record the position of the sample relative to the focal point of the objective lens as a function of time;

a light detector;

a time correlated single photon counting board, the board interfaced with the laser and with the light detector; and

a computer, the computer interfaced with the time correlated single photon counting board;

wherein the laser emits a light beam directed through the objective lens, the objective lens focuses the light beam on the sample on the stage to thereby cause some or all of the molecules in the sample to emit fluorescence;

wherein at least a portion of the fluorescence passes through the objective to the light detector, the light detector detecting the fluorescence to thereby generate electrical pulses;

wherein the electrical pulses are sensed by the computer-interfaced time correlated single photon counting board to thereby determine a fluorescence lifetime of the sample, the fluorescence lifetime being the period of time between the emission of light by the pulse laser and the emission of the fluorescence from the sample, and to record the time at which the fluorescence was detected by the light detector; and

wherein data regarding the fluorescence lifetime of the sample and the time at which the fluorescence was detected by the light detector are stored in the computer.

12. A computer interfaced scanning microscope system for detecting spatially imaged fluorescence lifetime and anisotropy, the system comprising:

a high frequency pulsed laser;

an objective lens;

a positioner located adjacent to the objective lens, the positioner including a stage designed to hold a sample, the positioner designed to move the stage relative to the objective lens

to thereby variably position the sample relative to the focal point of the objective lens, and the positioner further designed to sense and record the position of the sample relative to the focal point of the objective lens as a function of time;

a polarizer;

wavelength separators;

light detectors;

multiplexing electronics interfaced with the light detectors;

a time correlated single photon counting board, the board interfaced with the laser and the multiplexing electronics; and

a computer, the computer interfaced with the time correlated single photon counting board;

wherein the laser emits a light beam directed through the objective lens, the objective lens focuses the light beam on the sample on the stage to thereby cause some or all of the molecules in the sample to emit fluorescence;

wherein at least a portion of the fluorescence passes through the objective to the polarizer, wherein the fluorescence is split into two planes of polarized light, each of which passes through a wavelength separator, the wavelength separator separating each plane of polarized light into two fluorescent signals;

wherein the light detectors detect the fluorescent signals to thereby generate electrical pulses, the electrical pulses being sensed by the computer-interfaced time correlated single photon counting board to thereby determine the fluorescence lifetime and anisotropy of the sample; and

wherein the fluorescence lifetime and anisotropy of the sample are stored in the computer.

13. An automated method for screening and selecting cells, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells expressing an imagable property;

detecting and recording the imagable property;

identifying and recording locations containing cells expressing a desired characteristic of the imagable property and locations not containing cells expressing the desired characteristic of the imagable property; and

scanning lethal irradiation across the substrate through a high speed shutter, wherein the shutter is open only when the lethal irradiation is positioned over locations not containing cells expressing the desired characteristic of the imagable property to thereby kill the cells in such locations.

14. The method of claim 13, wherein the lethal irradiation is ultraviolet light.

15. The method of claim 13, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

16. An automated method for screening and selecting cells, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells expressing an imagable property;

detecting and recording the imagable property;

identifying and recording locations containing cells expressing a desired characteristic of the imagable property and locations not containing cells expressing the desired characteristic of the imagable property;

applying a sensitizing agent to the substrate, wherein the sensitizing agent is selected to render the sample of cells sensitive to light; and

scanning a light beam across the substrate through a high speed shutter, wherein the shutter is open only when the light beam is positioned over locations not containing cells expressing the desired characteristic of the imagable property to thereby kill the cells in such locations.

17. The method of claim 16 wherein the sensitizing agent is a DNA intercalating dye.

18. The method of claim 17 wherein the DNA intercalating dye is ethidium bromide.

19. The method of claim 16 wherein the sensitizing agent is a porphyrin.

20. The method of claim 16 wherein the sensitizing agent generates reactive oxygen species upon absorption of light.

21. An automated method for screening and selecting cells based on fluorescent amplitude, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the amplitude of the fluorescent light;

correlating the amplitude of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light;

generating a kill map of the substrate, the kill map indicating those locations not emitting fluorescent light with the desired amplitude; and

scanning lethal irradiation across the substrate through a high speed shutter, wherein the shutter is open only when the lethal irradiation is positioned over locations not emitting fluorescent light with the desired amplitude to thereby kill the cells in such locations.

22. The method of claim 21, wherein the lethal irradiation is ultraviolet light.

23. The method of claim 21, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

24. An automated method for screening and selecting cells based on fluorescent amplitude, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the amplitude of the fluorescent light;

comparing the amplitude of the fluorescent light to a pre-determined desirable fluorescent amplitude, to thereby determine whether the location contains a cell emitting fluorescent light with the desired amplitude; and

directing lethal irradiation to those locations that do not contain a cell emitting fluorescent light with the desired amplitude to thereby kill the cells in such locations.

25. The method of claim 24, wherein the lethal irradiation is ultraviolet light.

26. The method of claim 24, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

27. An automated method for screening and selecting cells based on fluorescent amplitude, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the amplitude of the fluorescent light;

correlating the amplitude of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light;

generating a kill map of the substrate, the kill map indicating those locations not emitting fluorescent light with the desired amplitude;

applying a sensitizing agent to the substrate, wherein the sensitizing agent is selected to render the sample of cells sensitive to light; and

scanning a light beam across the substrate through a high speed shutter, wherein the shutter is open only when the light beam is positioned over locations not emitting fluorescent light with the desired amplitude to thereby kill the cells in such locations.

28. The method of claim 27 wherein the sensitizing agent is a DNA intercalating dye.

29. The method of claim 28 wherein the DNA intercalating dye is ethidium bromide.

30. The method of claim 27 wherein the sensitizing agent is a porphyrin.

31. The method of claim 27 wherein the sensitizing agent generates reactive oxygen species upon absorption of light.

32. An automated method for screening and selecting cells based on fluorescent amplitude, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the amplitude of the fluorescent light;

correlating the amplitude of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light;

generating a kill map of the substrate, the kill map indicating those locations not emitting fluorescent light with the desired amplitude;

inducing the cells to synthesize an endogenous porphyrin precursor; and

scanning a light beam across the substrate through a high speed shutter, wherein the shutter is open only when the light beam is positioned over locations not emitting fluorescent light with the desired amplitude to thereby kill the cells in such locations.

33. An automated method for screening and selecting cells based on fluorescent lifetime, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the lifetime of the fluorescent light;

correlating the lifetime of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light;

generating a kill map of the substrate, the kill map indicating those locations not emitting fluorescent light with the desired lifetime; and

scanning lethal irradiation across the substrate through a high speed shutter, wherein the shutter is open only when the lethal irradiation is positioned over locations not emitting fluorescent light with the desired lifetime to thereby kill the cells in such locations.

34. The method of claim 33, wherein the lethal irradiation is ultraviolet light.

35. The method of claim33, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

36. An automated method for screening and selecting cells based on fluorescent lifetime, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the lifetime of the fluorescent light;

comparing the lifetime of the fluorescent light to a pre-determined desirable fluorescent lifetime, to thereby determine whether the location contains a cell emitting fluorescent light with the desired lifetime; and

directing lethal irradiation to those locations that do not contain a cell emitting fluorescent light with the desired lifetime to thereby kill the cells in such locations.

37. The method of claim 36, wherein the lethal irradiation is ultraviolet light.

38. The method of claim 36, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

39. An automated method for screening and selecting cells based on fluorescent lifetime, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the lifetime of the fluorescent light;

correlating the lifetime of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light;

generating a kill map of the substrate, the kill map indicating those locations not emitting fluorescent light with the desired lifetime;

applying a sensitizing agent to the substrate, wherein the sensitizing agent is selected to render the sample of cells sensitive to light; and

scanning a light beam across the substrate through a high speed shutter, wherein the shutter is open only when the light beam is positioned over locations not emitting fluorescent light with the desired lifetime to thereby kill the cells in such locations.

40. The method of claim 39 wherein the sensitizing agent is a DNA intercalating dye.

41. The method of claim 39 wherein the sensitizing agent is a porphyrin.

42. The method of claim 39 wherein the sensitizing agent generates a reactive oxygen species upon absorption of light.

43. An automated method for screening and selecting cells based on fluorescent lifetime, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells containing a fluorescent marker;

directing a light beam onto each location, thereby causing the fluorescent marker to emit fluorescent light;

automatically detecting the fluorescent light;

automatically measuring and recording the lifetime of the fluorescent light;

correlating the lifetime of the fluorescent light with the location containing the cell with the fluorescent marker emitting the fluorescent light;

generating a kill map of the substrate, the kill map indicating those locations not emitting fluorescent light with the desired lifetime;

inducing the cells to synthesize an endogenous porphyrin precursor; and

scanning a light beam across the substrate through a high speed shutter, wherein the shutter is open only when the light beam is positioned over locations not emitting fluorescent light with the desired lifetime to thereby kill the cells in such locations.

44. An automated method for screening and selecting cells, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells expressing an imagable property;

detecting and recording the imagable property;

identifying and recording locations containing cells expressing a desired characteristic of the imagable property and locations not containing cells expressing the desired characteristic of the imagable property; and

projecting lethal irradiation only onto those locations not containing cells expressing the desired characteristic of the imagable property to thereby selectively kill those cells.

45. The method of claim 44, wherein a computer-controlled projection device is used to project the lethal irradiation onto locations not containing cells expressing the desired characteristic of the imagable property.

46. The method of claim 44, wherein the lethal irradiation is ultraviolet light.

47. The method of claim 44, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

48. The method of claim 44, wherein the imagable property of the cells is sensed and recorded by a charge couple device based (CCD) camera.

49. An automated method for screening and selecting cells, the method comprising the steps of:

providing a substrate with multiple locations, at least some of which contain one or more cells expressing an imagable property;

detecting and recording the imagable property;

identifying and recording locations containing cells expressing a desired characteristic of the imagable property and locations not containing cells expressing the desired characteristic of the imagable property;

applying a sensitizing agent to the cells, wherein the sensitizing agent is selected to render the cells sensitive to light; and

projecting light only onto those locations not containing cells expressing the desired characteristic of the imagable property to thereby selectively kill those cells.

50. The method of claim 49 wherein the sensitizing agent is a DNA intercalating dye.

51. The method of claim 50, wherein the DNA intercalating dye is ethidium bromide.

52. The method of claim 49 wherein the sensitizing agent is a porphyrin.

53. The method of claim 49 wherein the sensitizing agent generates a reactive oxygen species upon absorption of light.

54. The method of claim 49, wherein the imagable property of the cells is sensed and recorded by a charge couple device based (CCD) camera.

55. The method of claim 49, wherein a computer-controlled projection device is used to project the light onto the cells not exhibiting the desired characteristic of the imagable property.

56. The method of claim 49, wherein the computer-controlled projection device is a digital light processor.

57. A method for selecting cells exhibiting desirable fluorescence properties, the method comprising the steps of:

providing a sample of cells, wherein the cells contain fluorescent markers that emit fluorescent light when excited;

exciting the sample of cells;

sensing and recording the fluorescence properties of the fluorescent light emitted by the cells in the sample;

generating a high resolution image map of the cells, based on the fluorescence properties of the cells, indicating those cells exhibiting desirable fluorescent properties as well as those cells not exhibiting desirable fluorescent properties; and

projecting lethal irradiation only onto those cells not exhibiting desirable fluorescence properties to thereby selectively kill those cells.

58. The method of claim 57, wherein a computer-controlled projection device is used to project the lethal irradiation onto the cells not exhibiting desirable fluorescence properties.

59. The method of claim 57, wherein the lethal irradiation is ultraviolet light.

60. The method of claim 57, wherein the lethal irradiation is multiphoton excitation of molecules in the cells.

61. The method of claim 57, wherein the fluorescence properties of the cells are sensed and recorded by a charge couple device based (CCD) camera.

62. A method for selecting cells exhibiting desirable fluorescence properties, the method comprising the steps of:

providing a sample of cells, wherein the cells contain fluorescent markers that emit fluorescent light when excited;

exciting the sample of cells;

sensing and recording the fluorescence properties of the fluorescent light emitted by the cells in the sample;

generating a high resolution image map of the cells, based on the fluorescence properties of the cells, indicating those cells exhibiting desirable fluorescent properties as well as those cells not exhibiting desirable fluorescent properties;

applying a sensitizing agent to the sample of cells, wherein the sensitizing agent is selected to render the sample of cells sensitive to light; and

projecting light only onto those cells not exhibiting desirable fluorescence properties to thereby selectively kill those cells.

63. The method of claim 62 wherein the sensitizing agent is a DNA intercalating dye.

64. The method of claim 62 wherein the sensitizing agent is a porphyrin.

65. The method of claim 62 wherein the sensitizing agent generates a reactive oxygen species upon absorption of light.

66. The method of claim 62, wherein the fluorescence properties of the cells are sensed and recorded by a charge couple device based (CCD) camera.

67. The method of claim 62, wherein a computer-controlled projection device is used to project the light onto the cells not exhibiting desirable fluorescent properties.

68. The method of claim 67, wherein the computer-controlled projection device is a digital light processor.

69. A method for selecting cells exhibiting desirable fluorescence properties, the method comprising the steps of:

providing a sample of cells, wherein the cells contain fluorescent markers that emit fluorescent light when excited;

exciting the sample of cells;

sensing and recording the fluorescence properties of the fluorescent light emitted by the cells in the sample;

generating a high resolution image map of the cells, based on the fluorescence properties of the cells, indicating those cells exhibiting desirable fluorescent properties as well as those cells not exhibiting desirable fluorescent properties;

inducing the cells to synthesize an endogenous porphyrin precursor; and

projecting light only onto those cells not exhibiting desirable fluorescence properties to thereby selectively kill those cells.

70. The method of claim 69, wherein the fluorescence properties of the cells are sensed and recorded by a charge couple device based (CCD) camera.

71. The method of claim 69, wherein a computer-controlled projection device is used to project the light onto the cells not exhibiting desirable fluorescent properties.

72. The method of claim 71, wherein the computer-controlled projection device is a digital light processor.

73. A method for selectively killing cells, the steps of the method comprising:

applying a diagnostic fluorophore to a population of cells, wherein some cells in the population show identifiable fluorescent characteristics compared to other cells in the population;

scanning the population of cells with a light beam from an ultrafast laser, the light beam having a wavelength and intensity selected to detect multiphoton excitation of the fluorophore without causing substantial cell death, wherein the fluorophore in the cells is excited by multiphoton absorption at a focal point of the light beam, causing the fluorophore to emit fluorescent light;

detecting the fluorescent light;

generating a high resolution kill map of the population of cells, the kill map indicating those cells emitting fluorescent light in response to the light beam;

scanning the population of cells with a high intensity light beam from the ultrafast laser, the high intensity light beam having a wavelength and intensity selected to kill the cells, through a high speed shutter, wherein the shutter is open only when the high intensity light beam is focused on cells emitting fluorescent light, to thereby selectively kill those cells.

74. The method of claim 73, wherein the diagnostic fluorophore is a porphyrin.

75. A method for selectively killing cells, the steps of the method comprising:

applying a diagnostic fluorophore to a population of cells, wherein some cells in the population selectively absorb the fluorophore at a higher rate than other cells in the population to thereby emit more fluorescent light when excited relative to the other cells;

focusing a light beam from an ultrafast laser on the population of cells, the light beam having a wavelength and intensity selected to detect multiphoton excitation of the fluorophore without causing substantial cell death, wherein the fluorophore in the cells is excited by multiphoton absorption at the focal point of the light beam, causing the fluorophore to emit fluorescent light;

detecting the fluorescent light and measuring the total quantity of fluorescent light emitted at the focal point of the light beam;

comparing the total quantity of fluorescent light emitted at the focal point of the light beam to a pre-determined total quantity of fluorescent light emitted by cells not selectively absorbing the fluorophore to thereby determine whether the cells at the focal point of the light beam have selectively absorbed the fluorophore at a higher rate; and

increasing the intensity of the light beam from the ultrafast light beam to thereby selectively kill only those cells that have selectively absorbed the fluorophore.

76. The method of claim 75, wherein the diagnostic fluorophore is a porphyrin.

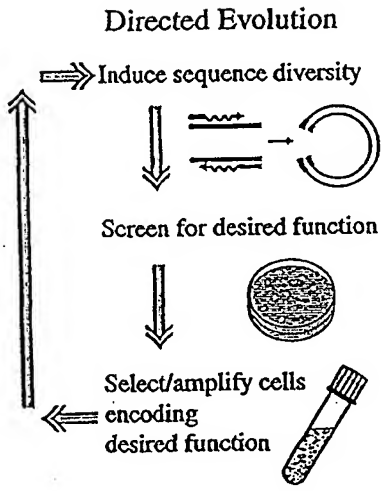


Figure 1. **The general scheme for directed evolution.**

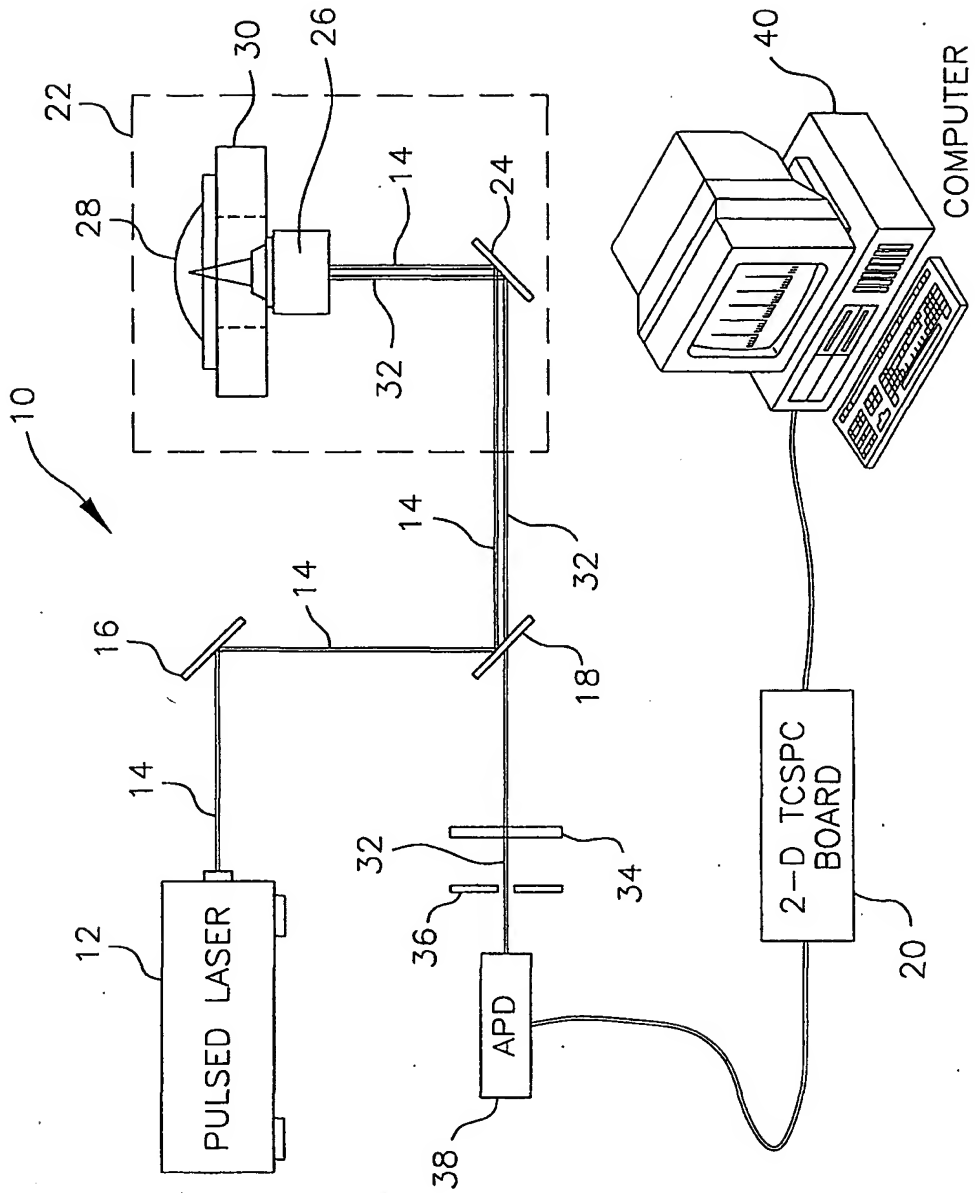

10
12
PULSED LASER
14
16
18
20
2-D TCSPC BOARD
22
24
26
28
30
32
34
36
38
40
APD
COMPUTER

FIG.2

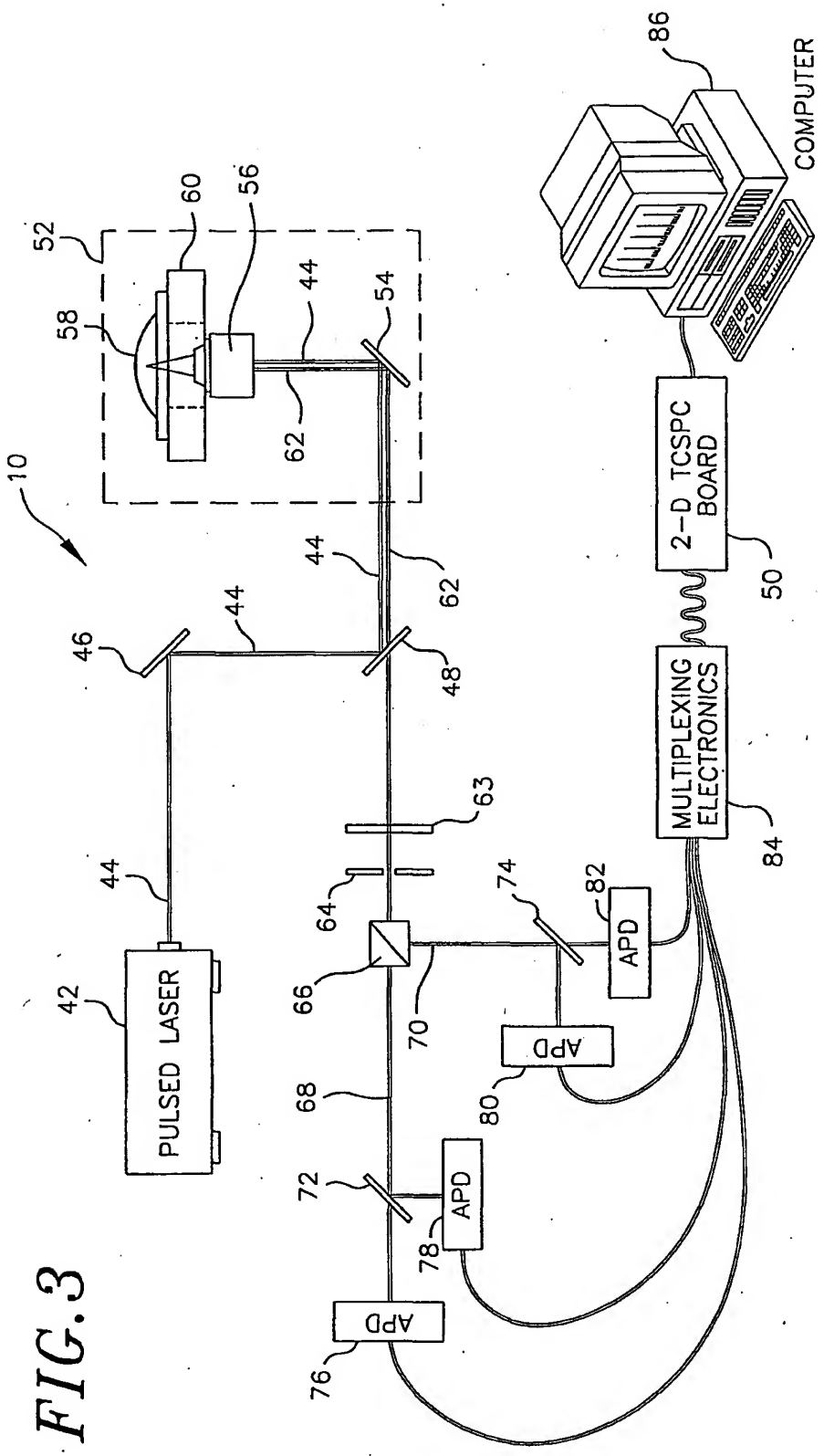
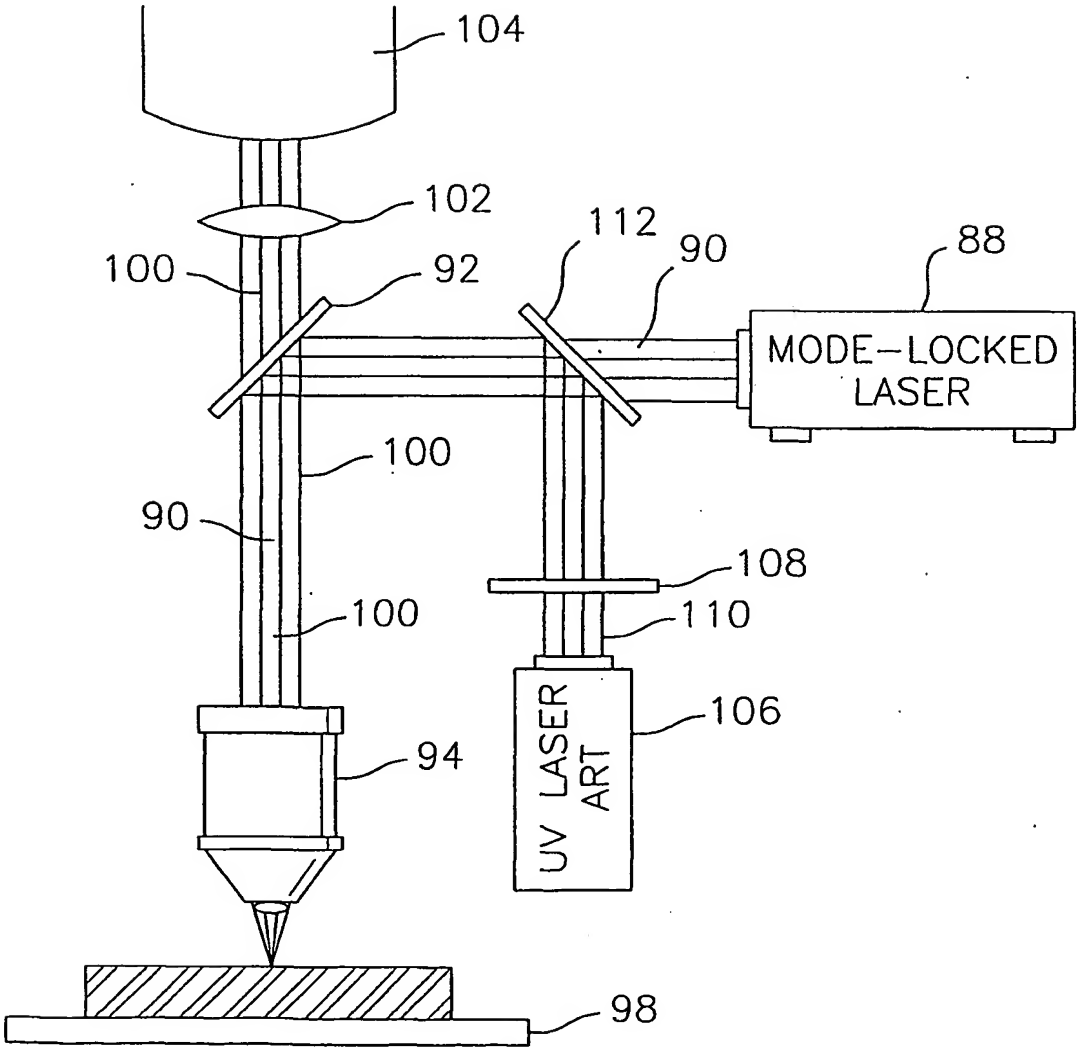

10
42
PULSED LASER
44
46
48
50
2-D TCSPC BOARD
52
54
56
58
60
62
63
64
66
68
70
72
74
76
78
80
82
84
MULTIPLEXING ELECTRONICS
86
COMPUTER
APD
APD
APD
APD

FIG. 3

FIG. 4


104
102
100
92
112
90
88
MODE-LOCKED LASER
100
90
108
100
110
UV LASER ART
106
94
98

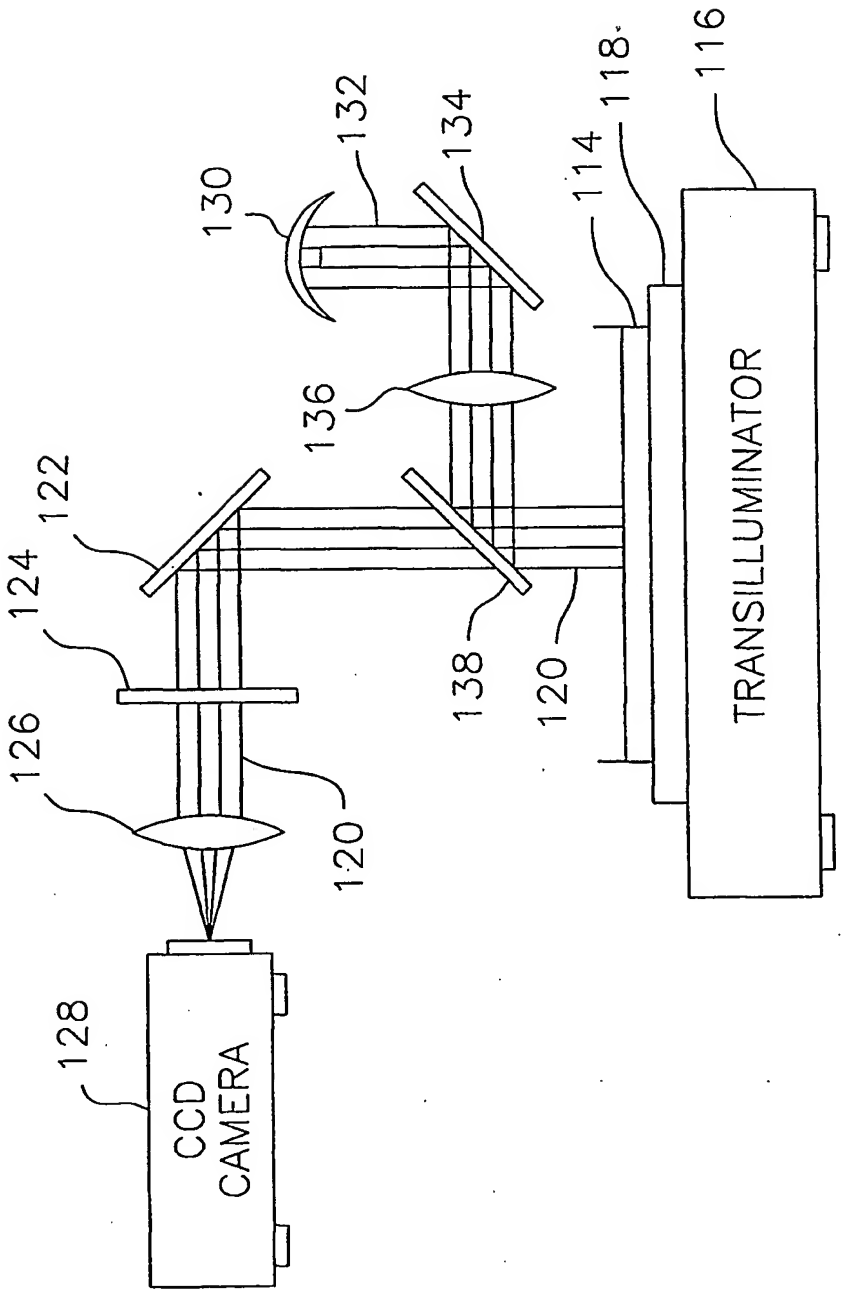

TRANSILLUMINATOR
CCD CAMERA
116
118
114
132
134
130
136
122
124
126
128
138
120
120

FIG. 5

Computer-Interfaced Scanning Fluorescence Lifetime Microscope Applied to Cell Screening and Selection in Directed Evolution Methodologies

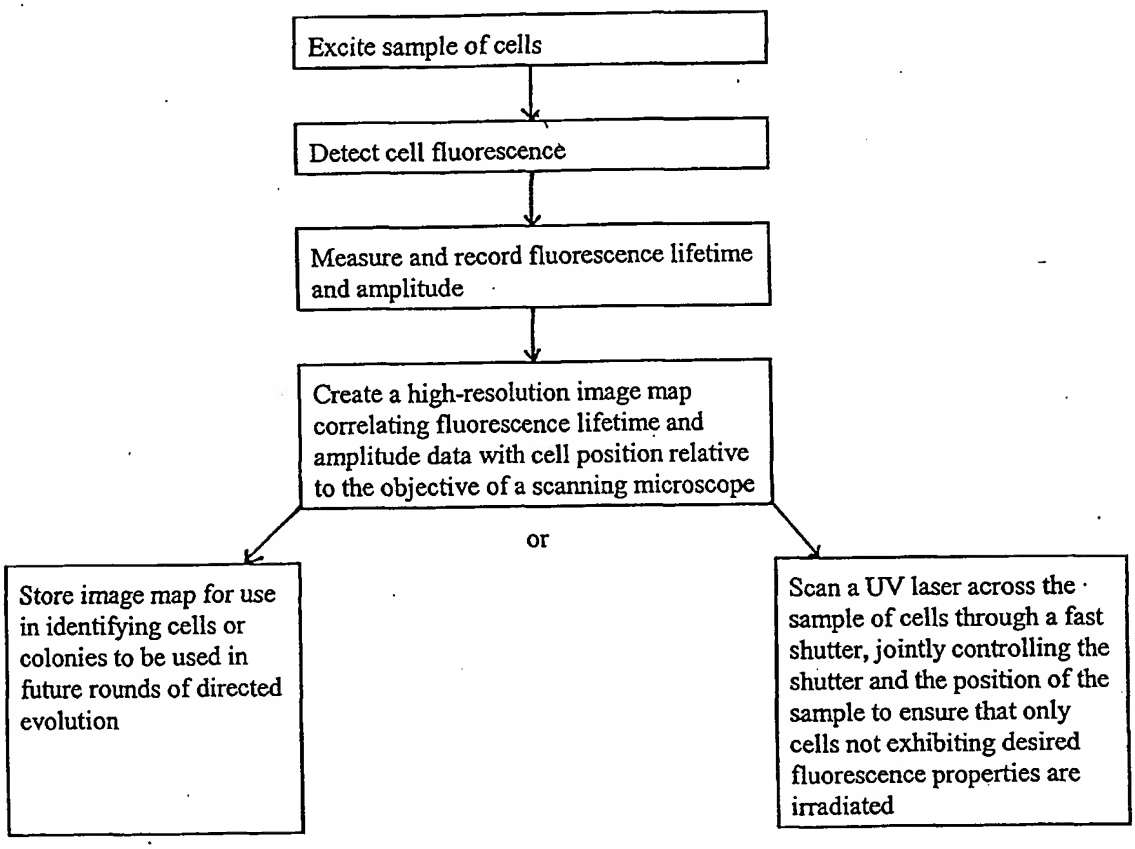


FIG. 6

Light Mediated Patterning in Cell Selection Using Imaging of Lethal Irradiation Applied to Directed Evolution

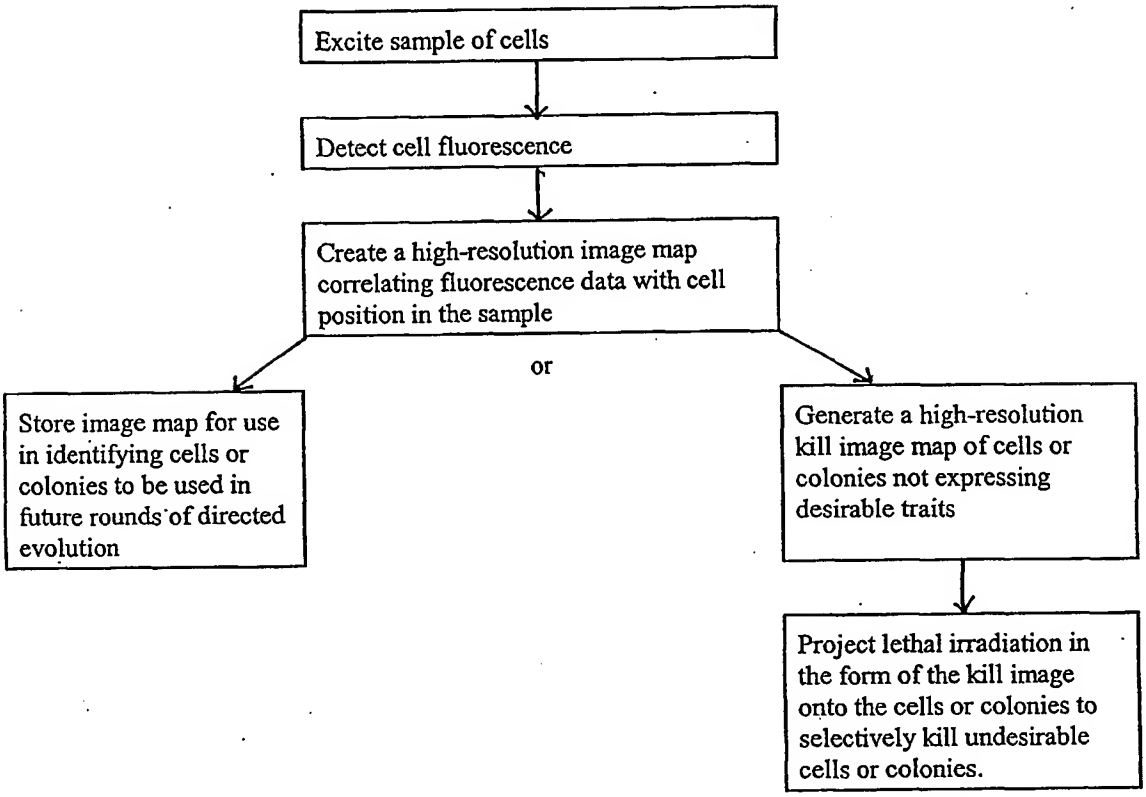


FIG. 7

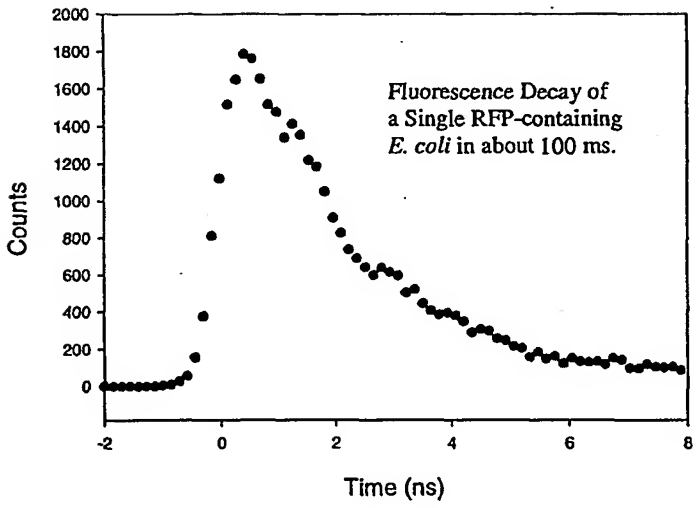

Fluorescence Decay of
a Single RFP-containing
E. coli in about 100 ms.
Counts
Time (ns)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-2
0
2
4
6
8

FIG. 8

Projected image.

A

Resulting growth on cell culture plate.

B

FIG. 9

Device for hydrodynamic focussing of a particle-suspension in a liquid flow cytophotometer

The invention relates to a device for liquid flow cytophotometer including a device for hydrodynamic focussing of a cell- or particle-suspension towards a measuring area, and an optical excitation- and detection-system.

Cytophotometry is an important operating method in cell biology research, especially in the field of comprehensive cancer research. Thus, it is considered important to investigate the abnormal growth in cell populations where new cells are created by means of cell division. During its synthesis phase the cell will double its DNA-content. In this way one gets two new cells when the cell divides (the mitotic phase). By measuring the DNA-content per cell it is possible to determine the distribution of the cells on the various cell cycle phases. The fraction of cells containing an increased DNA-content in a cell population can be a measure of the multiplying activity. It is important that the distribution of the cells in a cell population of various cell cycle phases can be determined with a great accuracy. Statistical errors can only be avoided by measuring several thousand cells. This necessitates that the individual measurements are done very fast.

The so-called liquid flow cytophotometry is a technique which is now applied for such measurements. Today there is an increasing use of this technique in connection with research as well as diagnostic purposes. The principle of such a method is to lead a limited flow of cells stained with a fluorescent dye, quantitatively bound to the cell components which are to be studied, through a beam of exciting light and then measure the intensity of the resulting fluorescence pulses. The distribution of the cells with regard to a certain component, such as DNA, can thus be determined with great accuracy and with a rate of the order of 10^3 per second. The cells are automatically transported to the measuring spot in a liquid flow, usually water.

Thus, the cells are not spread on a glass plate, but are kept in a liquid suspension. This suspension is driven through a capillary tube, and by means of a concentric sheath flow flowing around the tube mentioned above and in the same direction as the cells and containing no particles, the cell flow is hydrodynamically focussed so that the cells pass through the strictly limited area in the measuring focus of the cytophotometer. The cells pass by one after the other through this measuring area at high speed, just like mentioned above.

The measuring of the cell components is done by means of a microfluorometer. As mentioned above, the cell component must be stained with a fluorescent dye. When a cell containing such a fluorescent dye passes through the focussing area of the microscope lens, it excites fluorescent light which is collected by the lens and then lead to a photomultiplier. The signal from this photomultiplier is registered and expresses the cell-contents of the component in question.

A well-known liquid flow cytophotometer (US—A—3 738 759) applies the technique mentioned above. It comprises a closed system including a sheath flow measuring chamber. This chamber consists of a glass- or metal-body with channels in a T-form. By means of suction the sheath flow and the particle suspension which is to be measured are lead through the channel forming the T-form system, and accurately centered along the optical axis of the system. In this way one gets a measuring area at the peak of the T-form, i.e. at the area of the perpendicular channels constituting the arms of the T-form. One of the perpendicular channels transports a cleansing agent, while the other represents a drainage channel for the fluid flow containing measured particles. Thus, by using this well-known technique one gets a supply of particles along the optical axis with a focussing of every particle lying in the measuring aperture level. The optical system which is applied here comprises a so-called oil immersion optics which is known to the expert. The optics is in contact with the liquid suspension containing the particles or the cells which are to be studied.

There are also known liquid flow cytophotometers described in the US-A 3 661 460 using closed sheath flow measuring chambers, but where the liquid flow is lead perpendicularly through the exciting light in the measuring area.

Another liquid flow cytophotometer is described in DE—A 2 709 399. Within a closed chamber a hydrodynamically focussed liquid flow of particles is directed at a fixed angle towards a transparent plate covering the chamber. The flow channel is bent like a knee in the portion where the particles pass the transparent plate, thus forming an edge defining two observation zones. The diameter of the flow channel around this edge is further narrowed, so that some times a blocking of the flow may occur. There are strong mechanical and hydrodynamic limitations regarding the knee angle and with respect to the angle between the cover plate and the bisectrix of the edge. For cleaning the inner side of the cover plate the chamber has to be disassembled. Observation is only possible by an incident light method directing the light through the cover plate.

The well-known liquid flow cytophotometers mentioned above are complicated, and that leads to high construction expenses. Nowadays there is an ever increasing demand for a simple and inexpensive instrument which can be used in connection with routine investigations. The present invention provides a construction using a standard fluorescence microscope —

preferable with immersion optics — with a suitable photometer, and hydrodynamic focussing of a particle suspension. This construction is relatively inexpensive, easy to operate and gives a high resolution and stability.

In the device according to the invention the focussing device is being formed as a separate nozzle assembly which is directed at a predetermined angle α to the optical axis y of the system towards a surface of a plate situated in the object plane of the optics, thus directing the laminar liquid flow through the open air towards this surface. In this way a laminar liquid flow of the suspension is obtained. In contrary to the state of the art it is pointed out that this device does not apply a closed chamber, wherein the particle suspension is lead and focussed, but that the liquid jet is passed towards the measuring area in the air. Using this invention the measuring area can be the surface of a transparent plate, for instance a replaceable cover glass, in contact with the optics. But it is also possible to have the optics on the same side of the plate as the nozzle assembly.

The present device provides measuring results at least as good as the best results obtained with the above mentioned constructions. Furthermore, the present device results in a much easier setting up and focussing of the instrument than is the case with well-known systems. Due to the measuring area and the nozzle being constructed as separate parts situated in air, the user can easier inspect and clean the instrument. Thus, the cover glass in the measuring area can easily be washed or replaced. Furthermore, it is easy to flush the hydrodynamic focussing device including the nozzle. As the nozzle assembly is adjustable in relation to the optical axis of the system, various angles of incidence can be obtained for the liquid jet containing particles.

Thus, the nozzle assembly can be turned between a vertical and a horizontal position in relation to the level of the measuring area. The adjustable device of the nozzle assembly makes it possible to measure asymetric effects of the particles or the cells which are being studied. This is of interest when one needs information about the form of the particles. Such effects are difficult to measure when the liquid jet is permanently vertically aimed at the measuring area, as is the case with the above mentioned well-known systems where a closed liquid flow chamber is applied.

A drainage device is situated in the periphery of the measuring area, and this device is preferable made by a tube connected to a suction pipe.

In the following the invention will be described with reference to the enclosed figure showing a schematic side view of the present device. The nozzle assembly is adjusted so that it forms an acute angle with the level of the measuring area.

The nozzle assembly 1 is placed in a holder 2 with an inlet tube 3 for the sample suspension containing particles which are to be studied. This inlet tube 3 dissolves into a thin tube which extends centrally and axially into the nozzle assembly 1. The holder 2 is provided with an inlet tube 5 for sheath flow liquid, and this tube leads into the nozzle assembly 1 so that the sheath flow liquid is able to flow around the cavity needle 4. The nozzle assembly has a nozzle 6 with its outlet over a cover glass 7 situated above and in contact with an immersion oil coating 8 on a microscope objective 9.

The figure shows that the cover glass 7 is resting on a holder 10 connected to the microscope stage. As mentioned above, the nozzle assembly 1 can be adjusted in relation to the optical axis of the system, i.e. between a vertical and a horizontal position, represented by the y-axis and the x-axis, respectively. In the figure the holder 2 with the nozzle assembly 1 and the nozzle 6 is inclined in relation to the y-axis of an acute angle α. In order to remove liquid from the cover glass 7 as this flows out of the nozzle 6 a drainage 12 connected to a suction pipe has been set up.

As for a further description of the liquid flow cytophotometer, describing how the present and schematically shown device is operated, reference is made to the literature in this field which is known to the specialist.

When using the present device in a liquid flow cytophotometer, a particle- or cell-suspension is lead through the tube (3). At the same time a sheath flow liquid is lead through the tube 5, and by means of the nozzle 6 on the nozzle assembly 1 these two components create a hydrodynamically focussed sample stream constituting a liquid flow in air, which is directed towards the microscope cover glass 7 on the objective system 8, 9. In this way a laminar well-defined and stable flowing area is obtained on the cover-glass 7. This can be observed through the fluorescence microscope in incident light, i.e. with the excitation light focussed through the objective 9. The liquid is removed from the cover glass 7 by means of the drainage 12.

It has been found that large angles of incidence, for instance $\alpha = 70°$, give somewhat better results than those obtained when using other settings of the angle of incidence, for instance $\alpha = 0°$, i.e. the liquid flow is lead perpendicularly onto the cover glass 7.

Generally, the present device may be applied in connection with any fluorescence microscope with the illumination through the objective. The high speed of the liquid flow in the air (approximately 10 m/sec.) and the laminar flowing pattern on the cover glass has the effect that the system may be set up in any direction. The present device enables the specialist to set up a liquid flow cytophotometer which is superior as regards resolution, simplicity and rational use,

and which makes it possible to obtain measuring results at least as good as those obtained by well-known commercially available systems.

When set up vertically the present device may be applied for volume measurements based on the Coulter principle by applying a metal coating on the inner surface of the nozzle 6 and a ring on the upper surface of the cover glass 7, thus providing electrodes for the ionic current applied for such measurements. In this way the short liquid flow between the nozzle 6 and the cover glass 7 will constitute the sensing region of a change in the electric impedance induced by a passing particle or cell. Furthermore, light scattering measurements may be made by using a phase contrast objective and an annular detector situated in the shadow cast by the phase contrast ring. Large angles of incidence (i.e. 70° or more) are most practical for such light scattering measurements, because such angles of incidence make it possible to center a light scattering detector in the area of the optical axis.

Claims

1. Device for liquid flow cytophotometer including a device for hydrodynamic focussing (4,6) of a cell- or particle-suspension towards a measuring area, and an optical excitation- and detection-system (9), characterised by the focussing device being formed as a separate nozzle assembly (1) which is directed at a predetermined angle (α) to the optical axis (y) of the system towards a surface of a plate (7) situated in the object plane of the optics (9), thus directing laminar liquid flow through the open air towards this surface.

2. Device according to claim 1, characterised in that the plate (7) is transparent.

3. Device according to claim 1 or 2, characterised in that the plate (7) is replaceable.

4. Device according to claim 1, characterised in that the nozzle assembly (1) is adjustable with respect to the optical axis (y).

5. Device according to claim 1, characterised by a drainage device (12) — made by a tube connected to a suction pipe — being situated in the periphery of the measuring area.

Revendications

1. Dispositif pour un cytophotomètre à écoulement liquide comprenant un dispositif pour la focalisation hydrodynamique (4, 6) d'une suspension de cellules ou de particules vers une zone de mesure et un système d'excitation et de détection optique (9), caractérisé en ce que le dispositif de focalisation a la forme d'un ensemble séparé d'une tubulure (1) qui est dirigé à un angle prédéterminé (α) par rapport à l'axe optique (y) du système vers une surface d'une plaque (7) située dans le plan objet du système optique (9), afin de diriger ainsi un écoulement liquide laminaire à travers l'air libre, vers cette surface.

2. Dispositif selon la revendication 1, caractérisé en ce que la plaque (7) est transparente.

3. Dispositif selon la revendication 1 ou 2, caractérisé en ce que la plaque (7) est remplaçable.

4. Dispositif selon la revendication 1, caractérisé en ce que l'ensemble de la tubulure (1) est réglable par rapport à l'axe optique (y).

5. Dispositif selon la revendication 1, caractérisé par un dispositif de drainage (12) formé d'un tube connecté à un tube d'aspiration, qui est situé dans le pourtour de la zone de mesure.

Patentansprüche

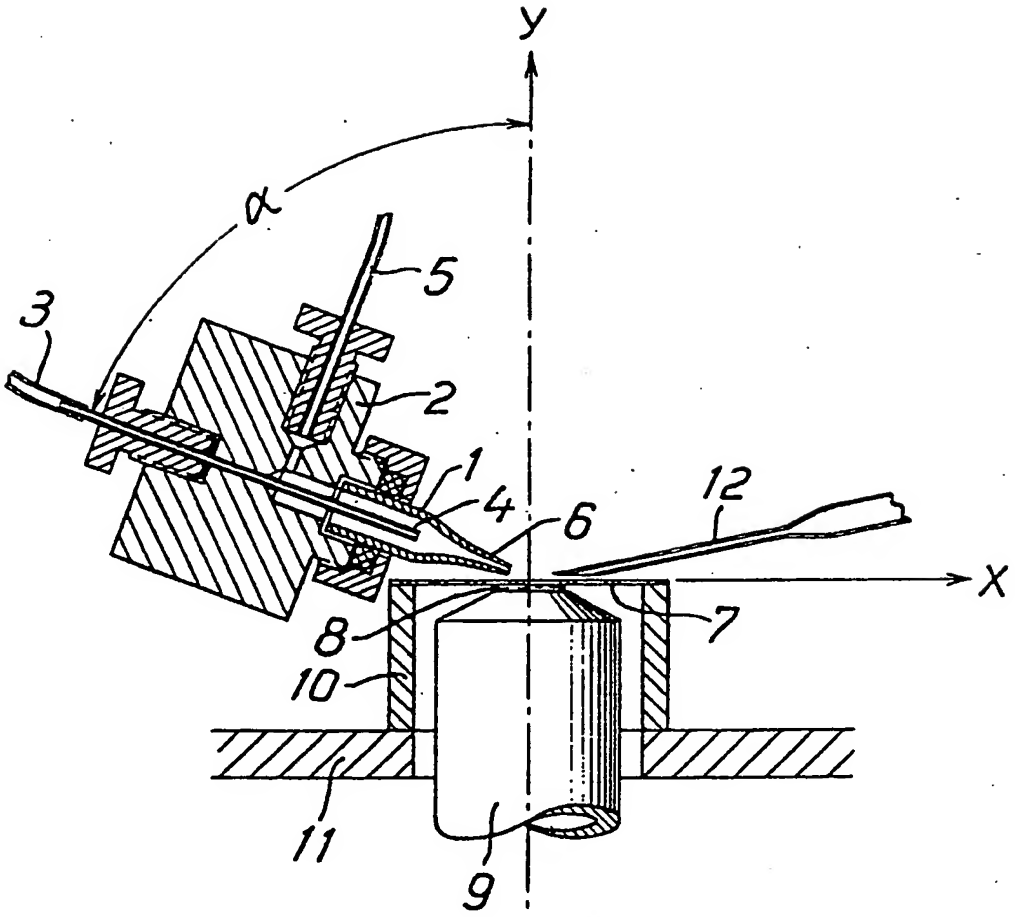
1. Vorrichtung für Durchfluß-Zytophotometer mit einer Vorrichtung (4, 6) zum hydrodynamischen Fokussieren eine Zellen- oder Partikelsuspension auf einen Meßbereich und einem optischen Anregungs- und Detektorsystem (9), dadurch gekennzeichnet, daß die Fokussiervorrichtung als eine getrennte Düsenanordnung (1) ausgebildet ist, die unter einem vorgegebenen Winkel (α) mit der optischen Achse (y) des Systems gegen die Oberfläche einer Platte (7) gerichtet ist, welche in der Objektebene des optischen Systems (9) angeordnet ist, so daß ein laminarer Flüssigkeitsstrom durch die freie Luft gegen diese Oberfläche gerichtet wird.

2. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die Platte (7) transparent ist.

3. Vorrichtung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die Platte (7) auswechselbar ist.

4. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die Düsenanordnung (1) in Bezug auf die optische Achse (y) einstellbar ist.

5. Vorrichtung nach Anspruch 1, gekennzeichnet durch eine Absaugvorrichtung (12)-gebildet von einer mit einer Absaugleitung verbundenen Röhre — welche am Rand des Meßbereichs angeordnet ist.


y
α
5
3
2
1
4
6
12
X
8
7
10
11
9